

LITHOLOGY A IN EETA79001 - PRODUCT OF IMPACT MELTING ON MARS. D.W. Mittlefehldt¹, D.J. Lindstrom², M.M. Lindstrom³, and R.R. Martinez⁴ ¹C23, Lockheed Martin ESS, 2400 Nasa Rd. 1, Houston, TX 77058, duck@snmail.jsc.nasa.gov, ²SN4, NASA/Johnson Space Center, Houston, TX 77058, david.j.lindstrom1@jsc.nasa.gov, ³SN2, NASA/Johnson Space Center, Houston, TX 77058, mlindstrom@snmail.jsc.nasa.gov, ⁴C23, Lockheed Martin ESS, 2400 Nasa Rd. 1, Houston, TX 77058, martinez@snmail.jsc.nasa.gov

Abstract². Martian meteorite EETA79001 is composed of two distinct magmatic lithologies, astutely named "A" and "B", joined by an igneous contact [1,2]. Lithology B is a coarse-grained, ferroan basalt, while lithology A is both finer-grained and more magnesian [1,2]. In addition, lithology A contains xenocrysts and xenoliths of olivine, orthopyroxene and chromite, which are petrologically similar to the major phases in martian lherzolites such as ALHA77005 [1,2]. A petrologic model to explain the petrographic and major element composition of lithology A is that it is a mixed magma composed of basalt like lithology B with a magma similar in composition to the martian lherzolites [3]. We have refined this magma-mixing model for lithology A by folding trace element data into the mixing calculations. We have performed micro-INAA on xenocryst-free groundmass samples drilled from thin section, and have begun petrologic and geochemical studies of additional samples of EETA79001, including xenocryst samples, and ALHA77005. We concur with [1,3] that lithology A is a mixed lithology, but unlike them, we believe that it is an impact melt. Lithology B is a large basalt xenolith in the impact melt.

Mixing Models. We have resurrected mixing calculations used to test mixing of components in lunar soils [4] to test binary mixing models for lithology A. Lithology B was always used as the basaltic component, while we separately tested the light and dark lithologies of ALHA77005, Chassigny and ALH 84001 as the ultramafic component in the mix. The best fit for bulk lithology A was obtained for a mix of 44% lithology B and 56% ALHA77005 light lithology. The light lithology of ALHA77005 is the coarse-grained, poikilitic textured material believed to be enriched in cumulus minerals [5], and is depleted in incompatible trace elements [6]. Our calculated mix contains too much of the most incompatible elements (e.g. La, Sm), suggesting that the ultramafic component in the mix is poorer in incompatible elements than is ALHA77005 light lithology. The distribution of incompatible trace elements in all analyses of ALHA77005 shows that even the light lithology samples are dominated by a trapped melt component. Therefore, the ultramafic component of the lithology A mix is plausibly a lherzolite containing less trapped melt than ALHA77005 light lithology.

Micro-INAA. We have analyzed 15 samples of ~30-40 µg mass for a suite of major and trace elements using micro-INAA procedures developed at JSC [7]. The micro-cores, ~500 µm diameter by ~60 µm thick, were drilled from regions free of xenocryst material, and were positioned to be as representative of the lithology A groundmass as possible. Because the size of the samples is comparable to the mean

grain size of the groundmass (~150 µm, [1]), heterogeneity is a problem. In fact, comparison of Na, Ca and Sc data for the groundmass samples with those for bulk lithologies A and B and ALHA77005 suggests that the groundmass samples are slightly enriched in pyroxene relative to maskelynite compared to true groundmass (Fig. 1). The transition elements Sc, Cr and Co are dominantly in the pyroxene component, and Co/Sc-Cr/Sc systematics can be used to estimate the dissolved ultramafic component in the groundmass. (Although chromite heterogeneity might be expected to play havoc with the Cr content of the samples, the distribution of the data, plus comparison with a sample containing an unusually large chromite, indicate that either chromite is homogeneously distributed in the micro-cores, or is at too low a modal abundance to substantially affect the Cr data.) Based on the transition element data, we estimate that the groundmass contains roughly 20-25% dissolved ultramafic component similar to martian lherzolites (Fig. 2). This estimate is insensitive to the problem of pyroxene-maskelynite heterogeneity mentioned above.

The lithology A groundmass samples are enriched in Au compared to lithology B and martian lherzolites, and sparse literature data show that the same is true for bulk lithology A (groundmass plus xenocrysts) (Fig. 3). This Au-enrichment does not appear to be anthropogenic in origin as it shows up in both groundmass and bulk lithology A samples, which were prepared by different techniques and run in different labs, and not in lithology B samples, which generally have been prepared and run the same as lithology A samples. We conclude that the groundmass of lithology A was enriched in Au by natural processes. One possible explanation for the enrichment is that either the basaltic or ultramafic component in lithology A was enriched in Au. A second possible explanation is that there is a third component in the mix that is rich in Au, the most obvious candidate being chondritic material.

Origin of EETA79001. Internal igneous models for the formation of lithology A are i) it was formed by assimilation of lherzolite by basalt [1], or ii) it represents a mixture of basaltic and lherzolic magmas [3]. Assimilation of lherzolite by basalt is energetically unfavorable [3], even using the lower estimate for dissolved ultramafic component derived here from our groundmass data. Hence, this seems an unlikely scenario.

The magma mixing model posits that ultramafic melts similar in composition to the lherzolites were formed on Mars. Mixing of such a magma (melt with entrained phenocrysts) with basaltic magma like lithology B then produced a hybrid magma containing some unresorbed phenocrysts from the lherzolic magma. These latter are now petrographically observed as the xenocrysts in lithology

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A. Although xenocrysts are somewhat heterogeneously distributed in lithology A, this rock is relatively homogeneous; there are no cm-scale, extreme variations in texture of the groundmass. A lherzolitic magma will have a higher liquidus temperature than a basalt, probably by $\sim 200^\circ\text{C}$. In order to be fluid enough to intimately mix, the phenocryst content could not have been too high, as crystals increase the viscosity of a magma [8]. Therefore, we would expect the lherzolitic magma would not have been much below its liquidus temperature, and mixing with a colder basaltic magma should lead to quenching of the ultramafic magma. This would tend to inhibit intimate mixing on the cm-scale. While we do not believe that magma mixing would result in the textures observed in lithology A, we recognize that this belief is based on "soft" arguments that require rigorous testing.

If the Au excess in lithology A is derived from chondritic material, the implication is that lithology A is an impact melt, rather than the product of martian igneous processes. We believe that this is the most likely explanation for the geochemical features of lithology A because it also provides a ready explanation for the petrography of EETA79001. EETA79001 is an impact melt containing lithic clasts of the dominant target rocks, lherzolite like ALHA77005, LEW 88516 and Y-793605, and basalt as represented by lithology B.

The age of lithology A is calculated to be ~ 170 Ma by Rb-Sr [9]. If we are correct that lithology A is an impact melt, then this age puts a lower limit on the time of impact melting. Lithology B, ALHA77005, Shergotty and Zagami all yield essentially the same Rb-Sr ages. Either the impact event occurred at about the same time as the volcanism that produced these other rocks, or all of them had their Rb-Sr ages reset by an impact event that produced the shock damage in them. In the latter case, impact melting to produce lithology A must have occurred prior to ~ 170 Ma.

Affirmation of Murphy's Law. One problem with the chondritic contamination model is that, while we find excesses in Au, we do not find clear excesses in all siderophile elements. Within uncertainties, the Au/Co ratios of the groundmass samples are consistent with chondritic contamination, while the Au/Ni and possibly Au/Ir ratios of the groundmass samples are not. (We only obtained upper limits for Ir, but some of them are too low to be compatible with chondritic Au/Ir in the contaminant.) Earlier we suggested that other explanations for the Au enrichment are possible, other than chondritic contamination. We cannot rule out the possibility that lithology A was formed by mixing of magmas, one or both of which were enriched in Au, but it seems unlikely.

References. [1] McSween and Jarosewich (1983) *GCA* **47**, 1501; [2] Steele and Smith (1982) *PLPSC* **13**, JGR **89**, B612; [3] Wadhwa *et al.* (1994) *GCA* **58**, 4213; [4] Schonfeld and Meyer (1972) *PLSC* **3**, 1397; [5] Lundberg *et al.* (1990) *GCA* **54**, 2535; [6] Treiman *et al.* (1994) *Meteoritics* **29**, 581; [7] Lindstrom *et al.* (1994) *GCA* **58**, 1367; [8] Shaw *et al.* (1968) *AJS* **266**, 225; [9] Nyquist *et al.* (1986) *LPS* **XVII**, 624.

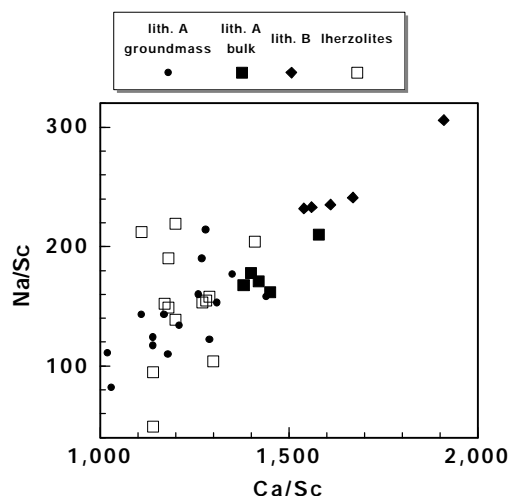


Figure 1. Groundmass samples of lithology A have lower Na/Sc and Ca/Sc ratios than the bulk, suggesting we systematically over sampled pyroxene, the major host for Sc, relative to maskelynite.

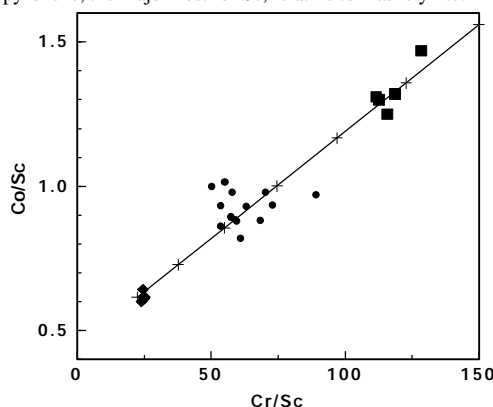


Figure 2. Transition elements suggest that the groundmass samples of lithology A contain about 20-25% dissolved lherzolite. The mixing line between lithology B and ALHA77005 light lithology has tick marks at every 10%. Symbols as in Figure 1.

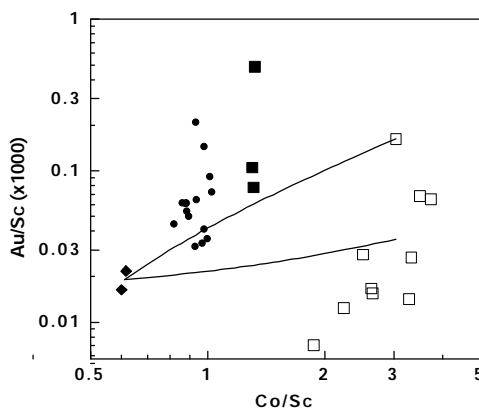


Figure 3. All groundmass and bulk lithology A samples show excess Au for mixing of lithology B and average lherzolite (lower line). Gold excess is present even using the most Au-rich lherzolite analysis as an end member (upper line). Symbols as in Figure 1.